December 10, 2012

Singing sands, squeal sounds and the stick-slip effect, a brief review. Requested by Physics Today

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A pleasant sound can be produced, with dominant frequency, $f_d \approx 700$ Hz and harmonics of f_d, when a finger, wetted with water, is drawn over a smooth surface such as a glass surface. It can be argued that the sound emission is due to vibrations in the finger skin, a few mm in thickness, when forced to slide over the glass surface. No sound can be produced when the same finger is wetted with a cooking oil.

Naturally, the intense sound emission begs the question as to the mechanism that can account for the transfer of energy from the pushing hand into vibration energy in the finger skin. The answer lies in the stick-slip effect which is based on the increase of the friction coefficient, μ, between the rubbing surfaces with a decrease in relative velocity, V_r, between the same surfaces and vice-versa, Patitsas (2010). Thus, if the finger is drawn along the x-axis with velocity, V_f, then, the relative velocity between the two surfaces is, $V_r = V_f - V_s$, where V_s is the skin velocity along the x-axis due to the vibration in the skin. With f_d= 700 Hz, V_s changes sign every 1/1400 s. During such a time interval, when V_s is positive, V_r is relatively low corresponding to the stick phase, when μ is relatively high and energy is transferred from the hand into the modes of the skin vibrations. During the following half cycle, V_s is negative resulting in the slip phase and lower μ. Evidently, the water, but not the oil, layer serves to effect such a change of μ with relative velocity, V_r.

Similarly, when a chalk is drawn over a porcelain plate or a black board, the tip of the chalk, one or two mm in thickness, becomes hot and fluidized somewhat, resulting in a squeal sound with $f_d \approx$2000 Hz. Evidently, the tip of the chalk assumes the role of the finger skin.

It is safe to argue that the stick-slip effect is responsible for all the squeal sounds around us, *i.e.*, a squealing door hinge, a squealing spinning tire, a squealing train rounding a curved track, a squealing cold snow, grain silo vibrations, vibrating rocks when rubbed one on another and possibly tectonic plates producing seismic waves. Then, could the strange phenomena of the singing sands be due to the same stick-slip effect? This is the case according to the recent paper by Patitsas (2012).

The acoustic phenomena of the singing (booming) dune sands when avalanching and of the singing (squeaking) beach sands when impacted by a pestle or stepped on has attracted the attention of explorers and travelers for many hundreds of years. Marco Polo (1295) was fascinated by the booming dune sounds in the Gobi Desert in China and Charles Darwin (1833) by the sonorous sound emitted when the hooves of the horses impacted a singing sand bed in Chile.

Bolton (1889) hypothesized that air cushions around the grains could result in collective expansion and contraction of all grain cushions in the grain mass giving rise to mass vibrations. However, when in 1975 a singing grain mass was impacted inside a vacuum jar, the mass vibration persisted.
Carus-Wilson (1881) was the first to recognize the role of the inter granular friction as the overtaking grains rub on the grains below, and Reynolds (1885) recognized that the grain mass undergoes dilation and contraction when it is sheared. Poynting and Thomson (1922) used the concept of dilation-contraction to argue that as grain layers slide over one another, the grains rise from their interstitial positions and then fall back into the next such positions giving rise to a periodic mass vibration. Bagnold (1954) elaborated on the dilation concept and determined the frequency of vibration for freely avalanching sand grains, f_d, as the inverse of the time required by a grain to overtake another. However, this line of thought implies nearly spherical and monosized grains and that is not the case in the real world. Furthermore, such hypotheses fail to account for the observed harmonics of f_d in the emitted signal. An excellent outline of such hypotheses can be found in the paper by Sholtz, Bretz and Nori (1997).

During the past eight years several approaches were reported in an attempt to determine the mechanism(s) behind the acoustic phenomena due to avalanching dune sand grains. The reader is referred to the papers by Andreotti (2004), Bonneau, Andreotti and Clement (2007, 2008), Andreotti and Bonneau (2009), Universities 6 and 7, Paris, France; Douady et al. (2006), Dagois-Bohy, Courrech Du Pont and Douady (2012), University 7, Paris, France. In all these reports there is no account of the harmonics of f_d or the low frequency content at about $0.3f_d$. Then, there are the reports by Vriend et al. (2007), Hunt and Vriend (2010), Cal. Institute of Tech., Pasadena, Cal., USA, where the harmonics of f_d are accounted for, but not the low frequency content. Most importantly, they cannot account for the booming emissions when the avalanching sand band is only about 3 cm in thickness. There is a variety of UTube presentations on line under the headings of, Song of the dunes, or Singing and booming sands.

Within the context of the stick-slip effect, Patitsas (2012), it is postulated that when the grains are forced to slide over one another during impact, elastic shear bands are formed at

the contact areas behaving elastically as short springs between the grains. Then, the grain columns below the impacting pestle can vibrate with a fundamental mode with wavelength equal to twice the column length, corresponding the frequency f_d, and a pestle mode where the entire column acts like a short spring with wavelength much larger than the column length, resulting in the low frequency content. Evidently, the higher modes of vibration correspond to the harmonics of f_d. It is argued that the pestle energy is transferred to the column modes of vibration via the stick-slip effect applicable in each contact shear band in a given grain column. Effectively, each contact shear band plays the role of the fluidized chalk tip, but with wavelength much larger than the shear band thickness. In this sense, a common beach sand does not sing when impacted since the stick-slip effect is not applicable at the grain contact areas. The grain shape is of little consequence, as is shown experimentally, Patitsas (2008, 2012).
The vibrations in the columns under the pestle become synchronized by their close contact with the pestle, which can also vibrate with the frequency f_d. Additionally, the strong interlocking between adjacent columns implies that only collective vibrations of the columns can occur.There is no need for a synchronization wave.

In the case of the avalanching booming sand, such columns are to be found in the slowly avalanching band between the static sand below and the fast moving 20 or so surface layers. The length of such columns is not predetermined and if the avalanching band thickness is more than about 1.5 cam, it self-adjusts so that f_d is equal to the collision frequency in the surface layers. If the band thickness is too low, then, the column length is also too low resulting in f_d higher that the collision frequency above, resulting in no booming. Clearly, such an approach can account for the harmonics of f_d and for the low frequency content. The synchronization of the grain column vibrations could come about from their interaction with the fast moving layers above, but most likely from the strong interlocking between adjacent columns, as in the case of the impacting pestle. A silent dune avalanche is most likely due to the non-applicability of the stick-slip effect at the grain contact areas. Normally, a moist dune sand does not boom.

All above papers are referenced in, A. J. Patitsas, Can J. Phys. 90: 611-631 (2012), except for, S. Dagois-Bohy, S. Courrech du Pont and S. Douady, Geophys. Res. Lett. 39: L20310(2012), and M. Hunt and N. Vriend, Annu. Rev. Earth Planet. Sci. 38: 281-301 (2010).